Receivers and Antennas for Low FrequencyField Strength Measurements

John K. Andrews, W1TAG/WD2XES

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There are very few commercially-made portable field strength meters that cover the range of the 2200 meter (135.7 - 137.8 kHz) band. Of those, most were designed for noise measurements, and don't allow for narrow bandwidth reception. Fortunately, this LF band is very forgiving of construction techniques and design compromises. Many "stray" effects that would ruin HF measurements are invisible at LF. So we have the possibility of combining a home-built antenna with a receiver that was designed for other purposes.

You probably already have a receiver that covers this frequency range, as many amateur radio receivers and transceivers now have general-coverage reception down to 100 kHz or lower. Would such a receiver be suitable for portable LF field strength measurements? Some considerations:

- The receiver needs to run on battery power, and you must lug the receiver, power source and antenna into areas free from power lines and other metallic conductors.
- The receiver must have the tuning accuracy to select your signal, and enough selectivity to separate it from interference. These should not be big issues for modern equipment.
- The receiver must run with the AGC off, and must be linear over at least a 20 dB range near its maximum sensitivity.
- The "S" meter will be useless, and you will have to provide an accurate indication of output audio from the last detector.
- You will need an accurate adjustable attenuator at the front end of the receiver, though the range may be limited in this application. You certainly don't need the wide signal strength range used in AM broadcast measurements.
- There must be a way to set the gain of the receiver while out in the field, and to calibrate that against some standard level.
- The gain of the receiver must be stable with temperature, or you must be willing to repeatedly check the gain calibration.

The author attempted to use an Icom R-75 receiver in this application. It met most of the above requirements, and the project was well underway before it became obvious that the gain was highly dependent on temperature. Since a field measurement setup is constantly being taken in and out of a vehicle in all sorts of weather, this is an issue! I finally determined that it would not be possible to make accurate measurements without repeated zig-zagging between the calibration and measurement modes. Investigation of the receiver's response to heat showed that the first IF area (near 60 MHz) was responsible for most of the gain variation. I did not wish to tackle this sort of problem, and the receiver is now being used for more normal tasks.

At this point, I spent considerable time deciding whether to construct a field-meter receiver from scratch. It would have been a fairly complicated project, both in terms of parts and time. Simple direct-conversion receivers would have extra responses from the audio image, and the nearby antenna would likely pick up the local oscillator signal. "Phasing" receivers are nice, but the adjustments are tough to maintain over wide temperature ranges. This indicated the need for a conventional superhet with crystal or mechanical filters for selectivity. The frequency readout would have to be pretty good, and the gain would have to be stable with temperature. It was a reasonable task, but I decided to not undertake it immediately.

Around this time, I acquired a second-hand HP 3586C selective-level meter (SLM) via eBay. Instruments like this were used for many years in the telephone industry to measure carrier levels of signals on coaxial cable and microwave circuits. Carrier telephone technology is all but obsolete now, and these meters are available at a fraction of their original cost. The HP SLM is basically a receiver that tunes from audio frequency to 32 MHz with very accurate frequency and level indications. Bandwidths of 3100, 400 and 20 Hz are available, and a variety of input terminations are accepted. The receiver is self-calibrating for level, with no external signal generator needed. The two catches are that this SLM is heavy, and requires 120/240 VAC power. Not an ideal thing for carrying out into the field! But it quickly became a frequently-used test instrument on my bench, and has long since paid for itself.

Having heard that telephone workers had “fried” these HP SLM’s by trying to use them with cheap power inverters on vehicle battery systems, I picked up a 600 watt sine-wave inverter, again via eBay. Some tests in the car showed that the 3586C was quite happy with the resulting 120 VAC power, so I proceeded to build a tripod-mounted loop antenna to be used in the field. This wasn’t small, either! But at this point, I did have a field-strength measuring setup that could be taken in the car to roadside stopping points. Following the calibration procedure that will be described in another paper, I made two sets of measurements on the WD2XES signal at distances out to about 10 km. While the readings were completely valid, two things were obvious:

- Each setup and measurement took enough time that I attracted considerable attention.
- It is difficult to avoid wires and metal fences when working from a car.

The HP SVM’s are not the only choices on the second-hand market. Some meters were clearly designed for portable use, and while it looked like the technology from the 1970's and earlier should be avoided, there were some regularly available later-model meters at good prices. Again, eBay to the rescue, and I found a Rycom 6041 in good condition for around $100. It has an internal battery, which had to be replaced, but an exact substitute was easily found . Otherwise, the meter was in excellent calibration, and all functions worked properly. It covers from the audio range up to 3.5 MHz, and the gain is calibrated at 250 kHz by throwing some switches and turning a gain knob for a -30 dBm indication. Digital readouts of both level and frequency are provided, and there is also a conventional tuning meter, which makes it easier to aim and tune the antenna properly. The Rycom 6040 appears to be a slightly older model, and should provide the same performance.

The Rycom meter reads levels in dBm referenced to a variety of impedances from 50 to 600 ohms. It also offers a choice of terminating or non-terminating input impedance, and balanced or unbalanced inputs. My field-strength measuring setup presently uses the balanced input, non-terminating, with readings referenced to dBm at 50 ohms. The first two choices will be explained shortly in the section on antennas, but the “dBm” business requires some discussion now. If the meter was set for a terminating, 50 ohm input, then a 1 milliwatt signal from a 50 ohm source would read 0 dBm on the Rycom. That corresponds to 223.6 milliVolts across 50 ohms. If the meter is set for a “bridging” (non-terminating) input, that same signal will read +6 “dBm”, as the input impedance of the Rycom will be high enough not to produce a voltage drop across the signal source’s internal 50 ohm impedance. But the reference level is still to the same 223.6 mV. So for the remainder of these papers about use of the Rycom meter for field measurements, it will be assumed that the dBm reference is to 223.6 mV without an actual 50 ohm termination. We will just be measuring voltage, not power.

Most of us are familiar with simple field-strength meters that use a whip antenna, a detector (possibly tuned) and a meter. A more sophisticated version of this could be used for measurements at LF. A short vertical antenna working into a preamp with a high-impedance input could produce the required sensitivity. As James Moritz (M0BMU) points out in his excellent paper, available on-line at: 'http://www.ofcom.org.uk/static/archive/ra/topics/research/topics/emc/measure/antproj.pdf' on the design of a portable field meter, a whip antenna has two problems in this application:

- The untuned preamp will have a dynamic range that may be exceeded by strong signals at MF or HF.
- The antenna will be sensitive to its height above ground, and proximity to the operator and other objects.

Additionally, there may be local screening effects from trees and other large objects that would disturb an electric field, but would not affect a magnetic field. While measurements should be taken in open areas if possible, valid readings can be had in tree-shaded areas with other types of antennas. For all of these reasons, short vertical antennas are not considered suitable for accurate field strength measurements at MF or LF.

A small (in terms of wavelength) loop antenna is preferred for measurements below 30 MHz, and certainly at LF. Assuming that the loop is properly balanced to the receiver's common (ground) connection, such a loop will be responsive only to *H* fields. Let's digress here, and talk about balance and shielding. Most classic texts on receiving loops will recommend that the loop be enclosed by a metallic conductor, with a small gap provided to prevent a "shorted turn." This is said to reduce electrostatic coupling to the loop, making it less sensitive to noise, hand capacitance, and so forth. In the case of an unbalanced loop, this is partially true, and you gain some advantage. But the need for the shielding can be eliminated by simply keeping the loop balanced. This lowers the *E*-field response, and makes the loop quite suitable for a hand-carried instrument. The balancing can either by done by a ferrite transformer or by an input amplifier working in balanced mode (i.e., having good common-mode rejection). These methods will be used in the discussions that follow.

Since our goal is to measure electromagnetic waves under far-field conditions, we will use the conventional *E/H* = 377 relationship, and express the measurement results in terms of the *E* field. The *E* field measured by a small loop producing a terminal voltage *Vloop* is given by:

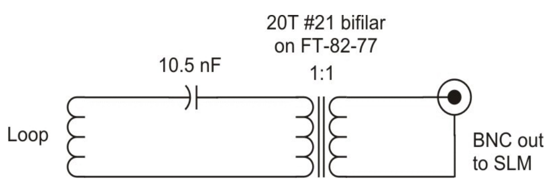
$$E = \frac{c \cdot Vloop}{2 \cdot \pi \cdot f \cdot n \cdot A}$$

Where:

c = 2.998 x 10^8 meters/sec
Vloop = loop terminal voltage, Volts
f = frequency, Hz
n = number of turns in the loop
A = area of loop in $meters^2$

That voltage will only be available if the receiver's input impedance is high enough not to load the loop circuit. "Bridging" is normally defined as 10 times the source impedance. Since that source includes resistance and reactance we have to consider both. An example may help:

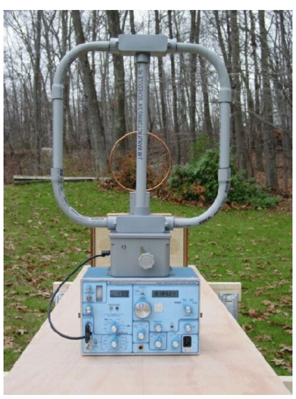
The loop pictured above which was used with the HP 3586C meter is 0.46 meters on a side, and contains



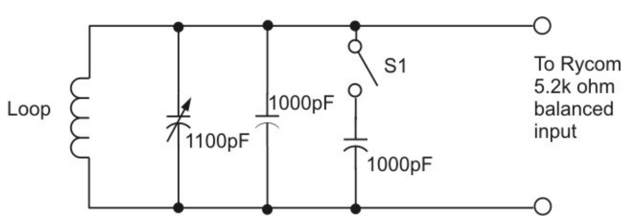
10 turns of wire. The measured impedance was 0.9 +j111 ohms at 137 kHz. To avoid dropping the voltage across that 111 ohms of reactance, the loop would have to be fed into a receiver input impedance of 10 times (or more) of that value, i.e., 1110 ohms. At the time, I wanted to use the 50 ohm input on the SLM. So I used the circuit below:

In this configuration, the 10.5 nF capacitor cancels the +j111 inductive reactance of the loop. The 1:1 transformer simply balances the loop with respect to the HP SLM's circuit ground. Thus the loop sees the 50 ohm inputof the SLM, and that is much greater than the 0.9 ohm resistance of the loop. The loaded Q of the circuit is low, and the tuning is broad enough to cover the whole 2200 meter band without the need for a variable capacitor. So the SLM's 50 ohm input would see the open-circuit voltage of the loop predicted by the equation above.

This was a neat solution, and it worked well. But it provided a signal of -90 to -100 dBm on the WD2XES signal in my usual measurement range of 3 to 10 km from the transmitter site. This was fine for the HP meter, which was very accurate to -120 dBm. But the Rycom 6041only reads down to -100 dBm, and accuracy is reduced between -95 and -100 dBm. I really needed about 20 dB of voltage gain to guarantee good readings out to 30 km or so. An external preamplifier would work, but it would not be included in the meter's calibration process out in the field. If the gain of that amp varied with temperature, voltage, or whatever, errors would result. Since the loop was already pretty big for hand-carrying, I decided against making it any larger. Then I started thinking about a parallel-tuned loop. The Rycom meter has a measured 5200 ohm input impedance in Bridging mode. If I added more turns to the loop and brought the reactance up to about 1/10 of that value, parallel tuning would give a loaded Q of about 10, and I would have my extra gain. Here's what followed:



Ignore the small copper loop in the center...it's part of a calibration setup that will be described in another paper. The loop on top of the Rycom is made of 1" PVC conduit, and has 20 turns of #14 stranded wire. The corners are pre-fabricated 90° "sweeps", and "T" conduit boxes are used at top and bottom. The vertical piece between the boxes is for rigidity only, and contains no wiring. The center to center spacing between the sides of the loop is approximately 0.46 meters (18 inches), and is not critical. The wires were pre-cut to length, and pulled through in one bundle. Splices (covered with heat-shrink tubing) are done in the upper conduit box. The two ends of the winding go through holes in the lower box through the lid of the PVC electrical box (measures 6"x6"x4.38"). All of that material was purchased at a local home-goods store (Lowe's). The electrical box contains an 1100 pF 3-gang variable capacitor and a couple of padding capacitors to set the tuning range of the loop. A pair of banana jacks on the side of the box bring out the tuned loop for connection to the Rycom meter. Here's the schematic:



The tuning range is about 125 to 150 kHz with S1 closed, and 145 to 198 kHz with it open. I measured the loaded Q of the loop/meter combination at 137 kHz by coupling a single-turn loop driven by a signal generator. The -3 dB points were 13 kHz apart, giving a Q of 10.5. This means that the voltage fed to the Rycom meter is 10.5 times the output voltage of the loop. Tuning is broad, and it is easy to correctly peak a signal while watching the analog meter on the Rycom front panel. Impedance measurement of the loop without the tuning capacitors shows 5.2 +j456 ohms at 137 kHz. A quick calculation estimates about 105 pF of inter-winding capacitance within the loop, so the true inductive reactance is about +j438 ohms.

I removed the original handle from the top of the Rycom case, and have since relocated it to the right side, as some assistance is needed when carrying the beast. The electrical box is bolted to the top of the case. A shielded pair is used to bring the two wires from the tuned loop down to the Rycom banana jacks. The shield is connected at the SLM end only, and is left floating at the loop box. There are no measurable hand capacitance effects to the loop or the cable. It is necessary to carefully measure the area of the loop for use in later calculations. I did that by measuring the center to center distance between the conduits, both horizontally and vertically, and multiplying to get the area. Then I laid the corner of the loop on some graph paper and traced the outside of the tubing. Setting the loop aside, I drew an arc at the center line of the loop, and counted squares on the graph paper for the area that would be missing from a full rectangle. I multiplied that by 4 to include all four sweeps, and subtracted it from the area of the rectangle. In my case, the area was 0.2026 $meters^2$. It is also necessary to know the equivalent radius of the loop if it were a circle of the same area, and that is 0.254 meters.

This paper has described the selection of a receiver and construction of an accompanying antenna that can be carried (lugged) into the field for signal strength measurements. Given the current prices of SLM's on the second-hand market, and the limited number of items to build the loop, this should be a cost-effective approach for amateur/experimental purposes. Subsequent papers will describe the calculation process, give tips on selecting and making field measurements, and present some results that I have had with the WD2XES operation.